Physics with Active Targets

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KU Leuven, Instituut voor Kern- en Stralingsfysica

BriX one-day meeting
Leuven, 23rd November 2015

Leuven and Active Targets

- Novel gaseous detectors
  for reaction and decay studies

- Core project: **ACTAR TPC**
  (GANIL, IPNO, CENBG, KUL, USC)
  ERC Starting Grant

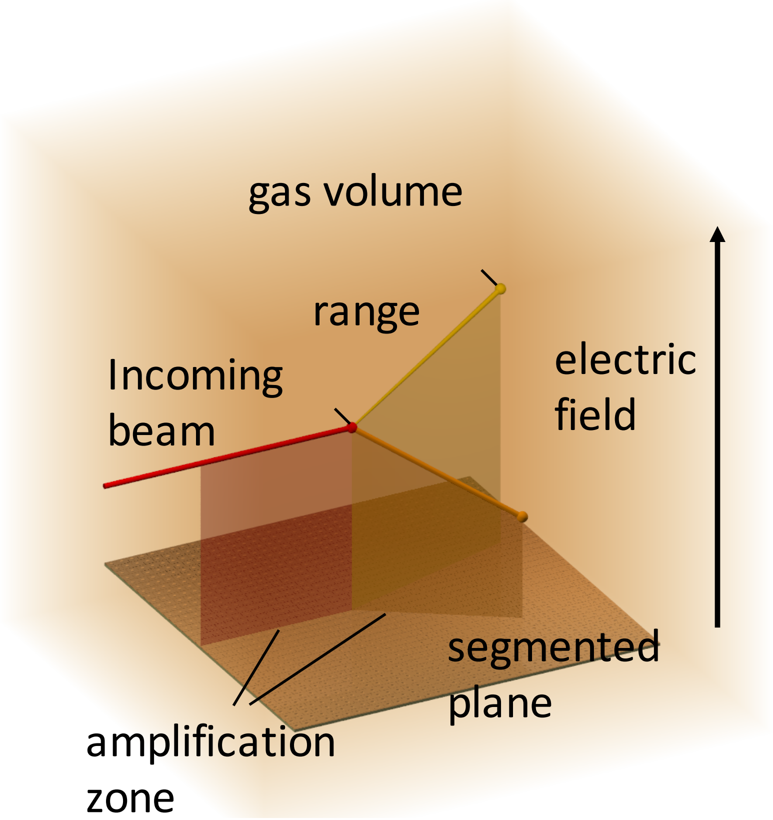
- KU Leuven project: **SpecMAT**
  Spectroscopy of exotic nuclei
  in a Magnetic Active Target
  ERC Consolidator Grant

- Plans for additional detectors
  - Active target for SPES
  - Active target for GR studies
  - "Gas-filled detectors and systems" – NA in ENSAR2

Detector concept: tracking

Time-Projection Chamber (TPC)
+ gas is the target

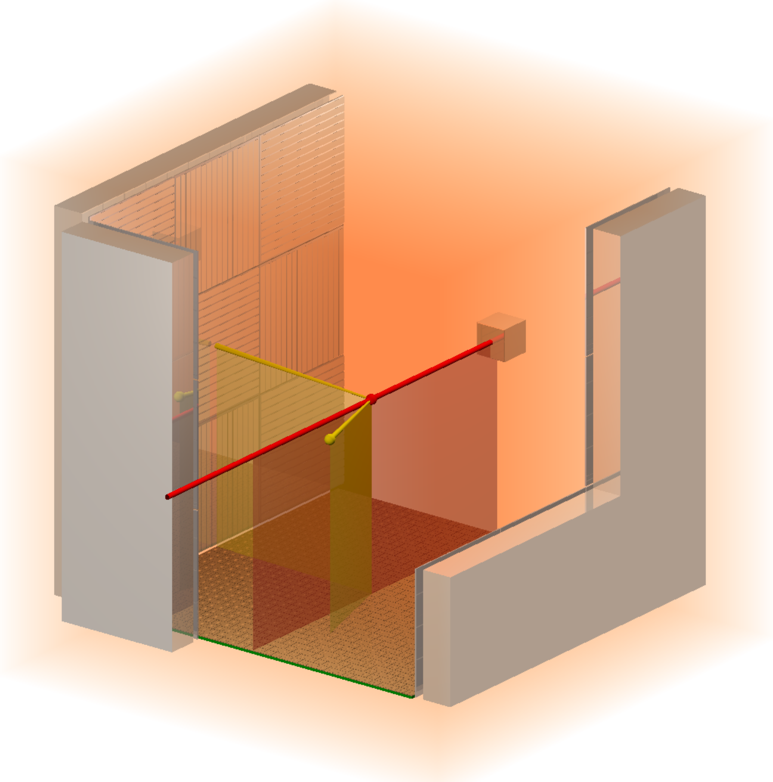
- Electrons produced by ionization drift to an amplification zone
- Signals collected on a segmented "pad" plane $\Rightarrow$ 2d-image of the track
- 3rd dimension from the drift time of the electrons
- Information:
  - angles
  - energy (from range or charge)
  - particle identification



Detector concept: tracking

Advantages

- Large target thickness
  → high luminosity
- Efficient:
  - 4π geometry
  - Low thresholds
- Extremely versatile
  - different gases and pressures
  - variable shape
  - auxiliary detectors



Comparison with high-energy devices

High-energy physics	Nuclear structure
Minimum ionising particles	Very high dynamic range
Trigger from ancillary detectors	Internal trigger
Complex reaction High occupancy Through-tracks	Low occupancy Stopped tracks
Resolution ≈50 μm	Resolution ≈1 mm

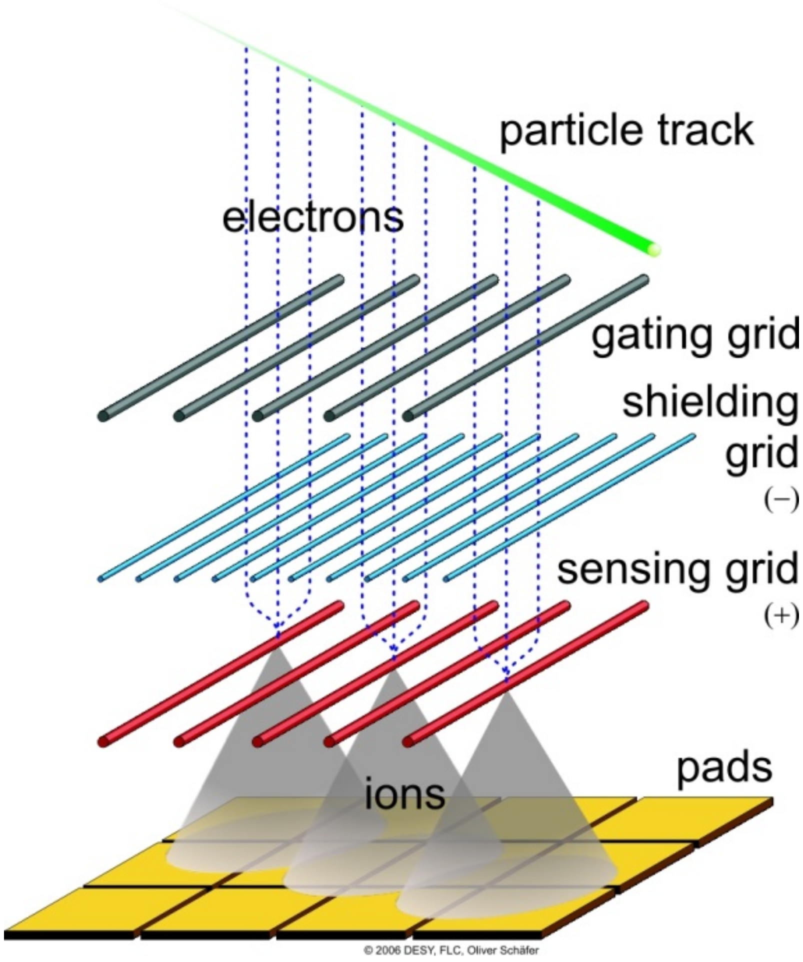
Amplification technology

From wires…

- Broad signals (induction)
- Mechanically complex, fragile

…to Micro-Pattern Gas Detectors

- Robust
- Reduced ion feedback



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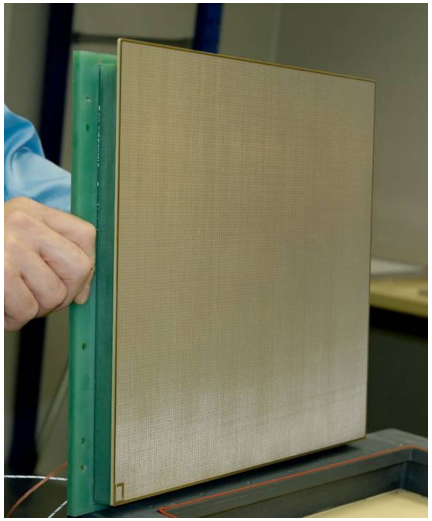
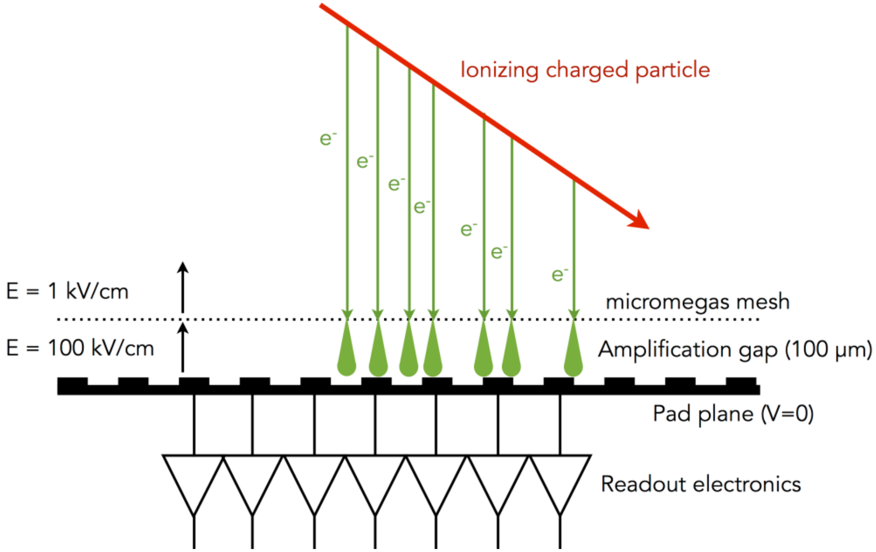


Micromegas

Y. Giomataris et al. NIMA 376 (1996) 29



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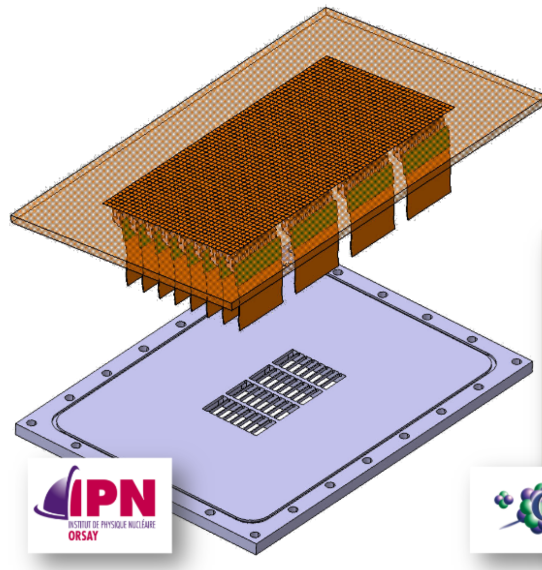
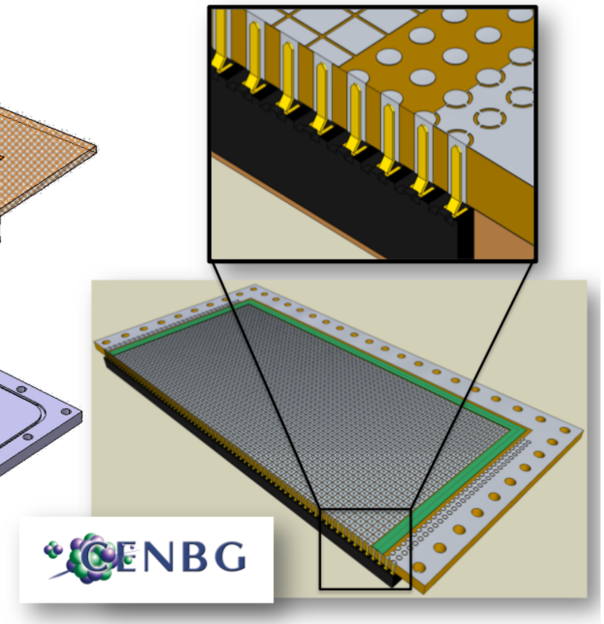
Amplification technology

Implementation

- IPNO solution:
  20-layer circuit board +
  micromegas
  glued on a metallic flange
- CENBG solution:
  - holes in metallic frame
  - connectors inserted
  - filled with molten tin
  - covered with epoxy and
  micromegas

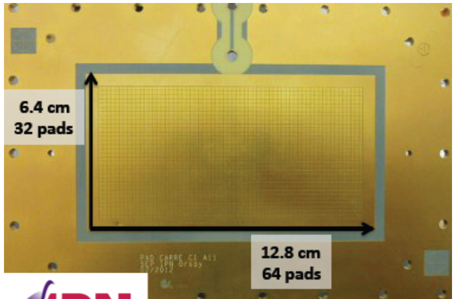


P. Rosier, IPNO

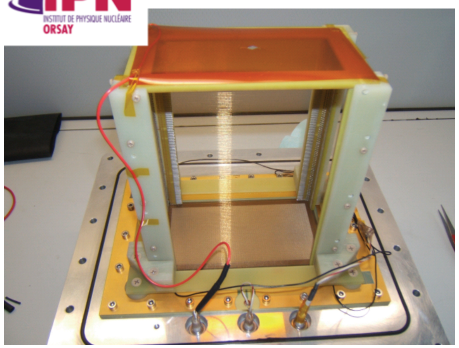


J. Pibernat, CENBG

Amplification technology

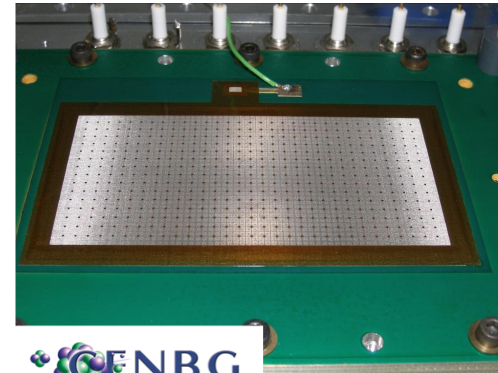


IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

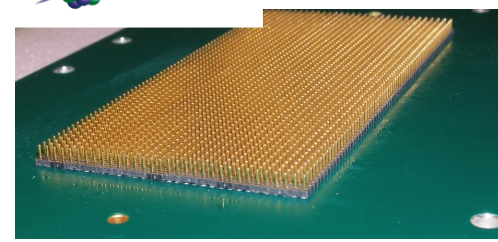


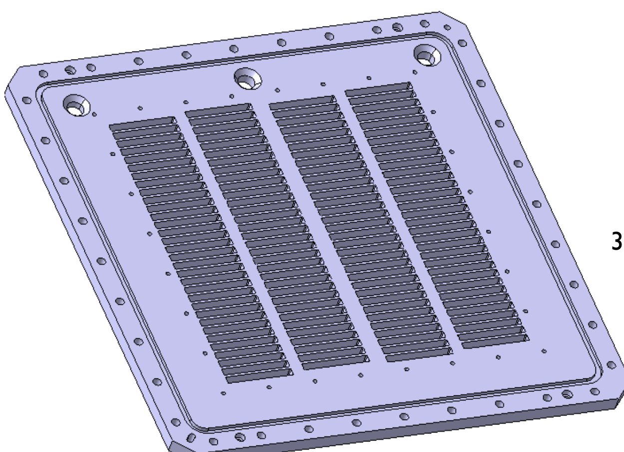
- Demonstrator:
  2048 pads 2x2 mm^2

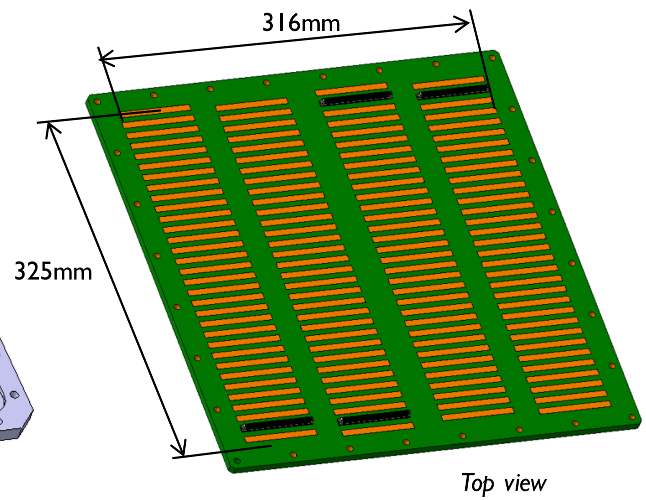
- Final detector:
  16384 pads 2x2 mm^2



CENBG





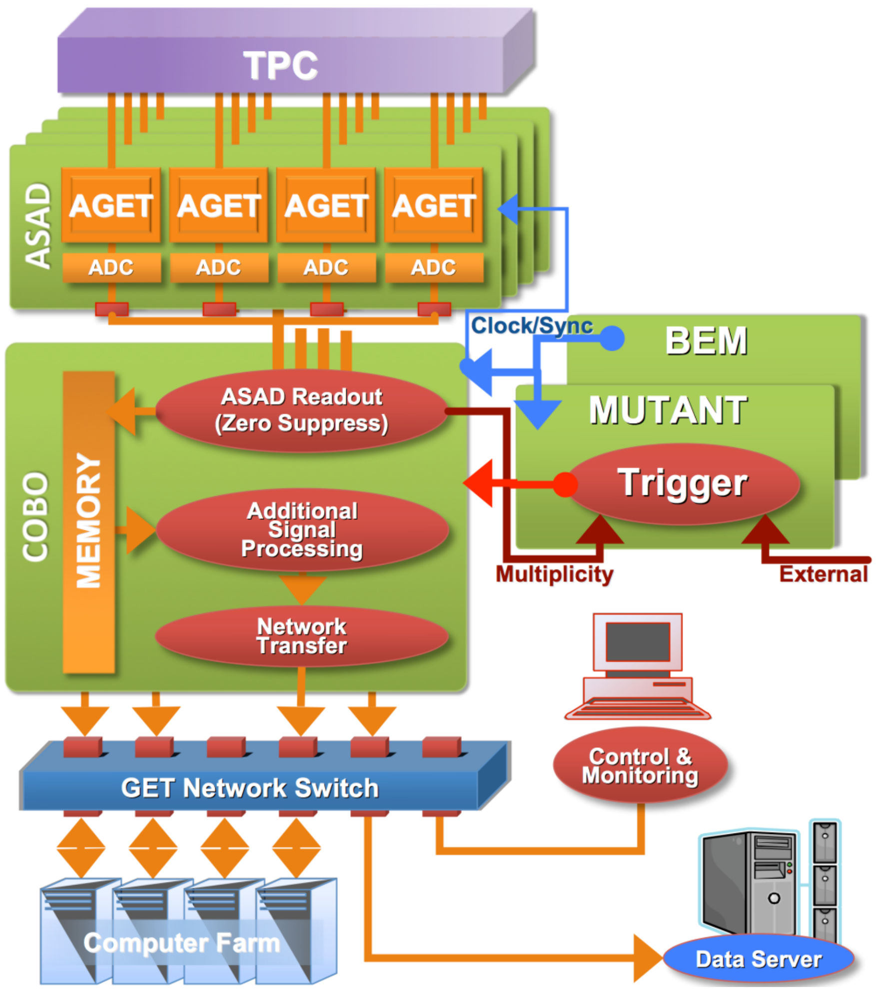


Electronics

GET – General Electronics for TPCs

CEA-Saclay, CENBG- Bordeaux, GANIL-Caen, NSCL

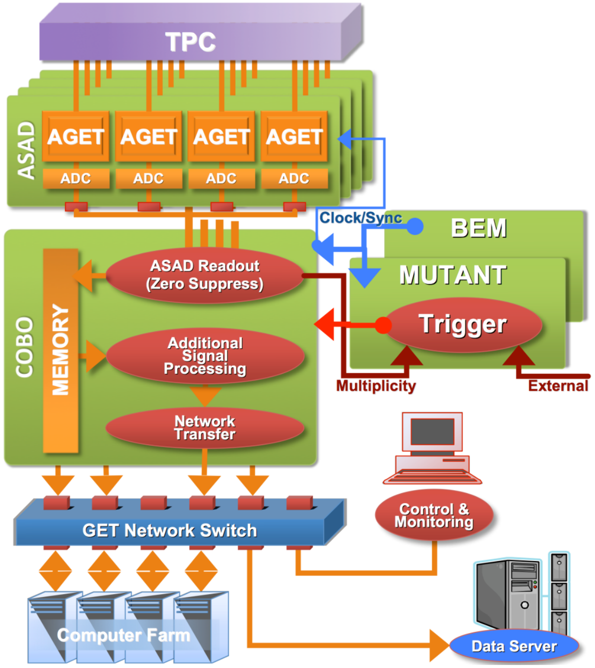
- High front-end density (up to 30 000 channels)
- High-rate throughput (selective readout, zero suppression)
- High dynamic range
- Versatile (amp factor, sampling)
- **Intelligent trigger**
  L0 external
  L1 multiplicity
  L2 topology



Electronics

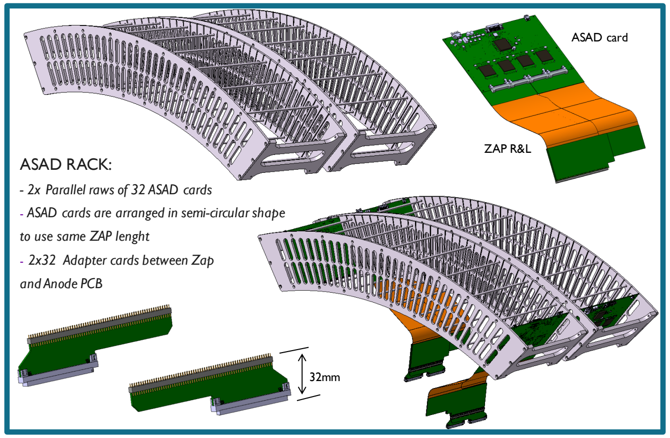
GET – General Electronics for TPCs

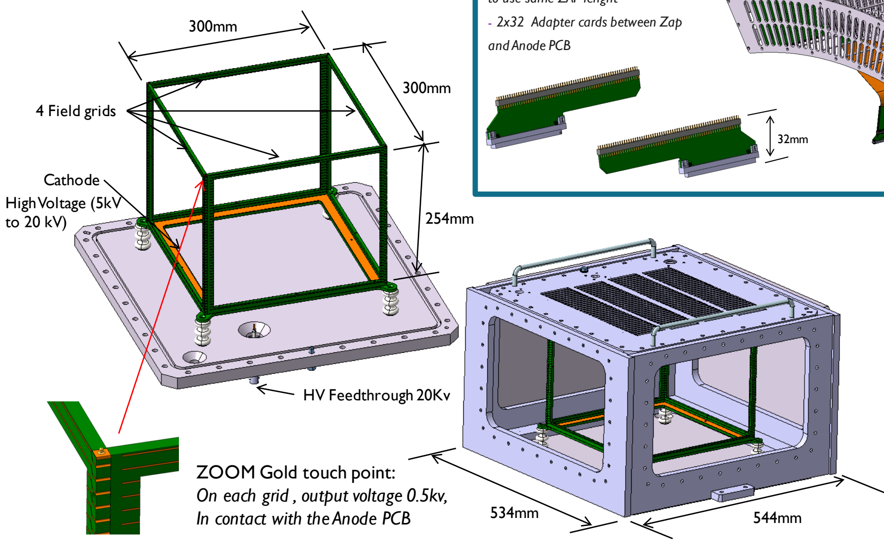
- Modules now available

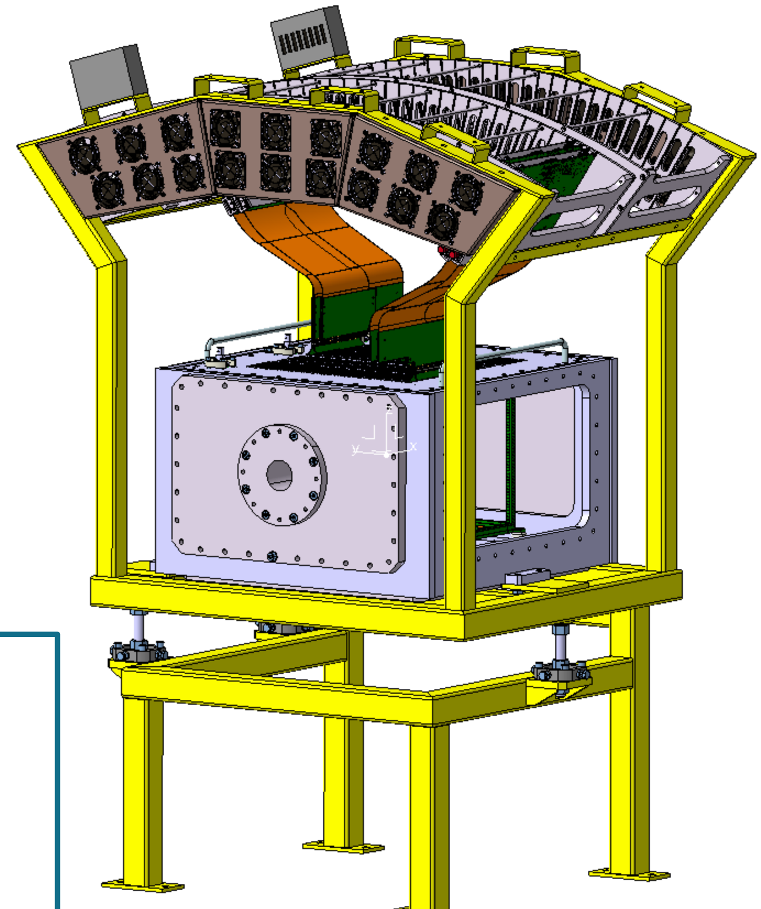


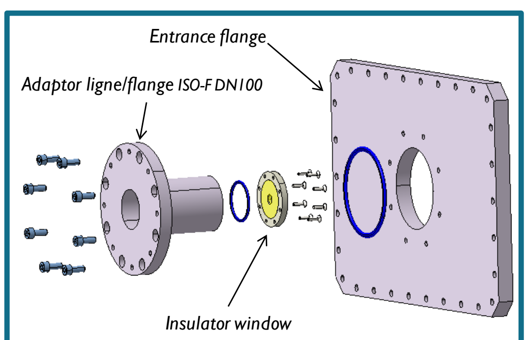
ACTAR TPC

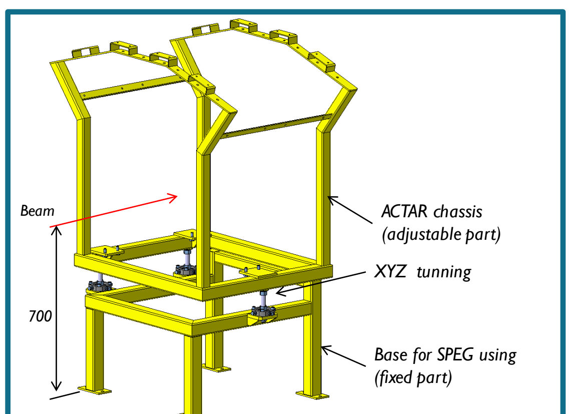
Work of P. Gangnant, GANIL







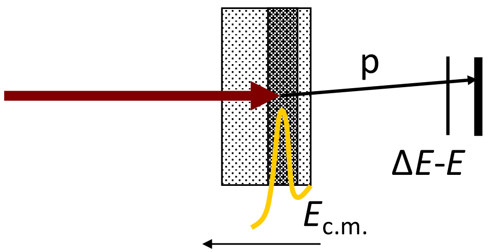


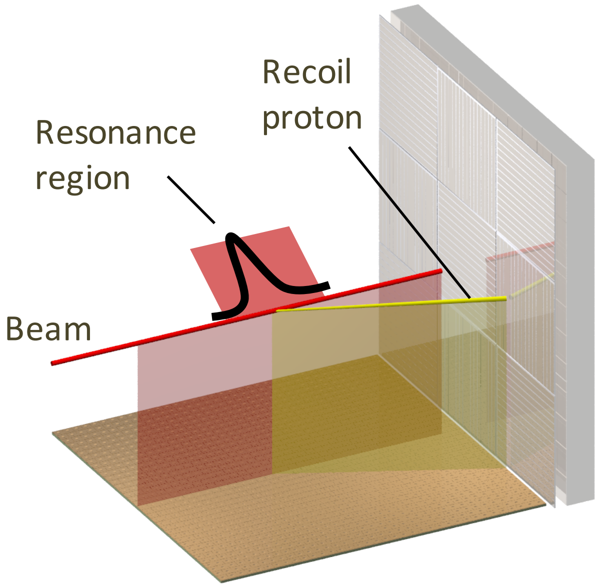


Physics I: resonant reactions

- Inverse kinematics: scan energy region by degrading the beam energy in the target
- In gas: usually limited to 180 degrees
- Active target: measurement of
  - reaction vertex
  - momentum of recoil particle
  - range scattered particle

  → identification of reaction channel
  identification of beam contaminants
  large angular coverage

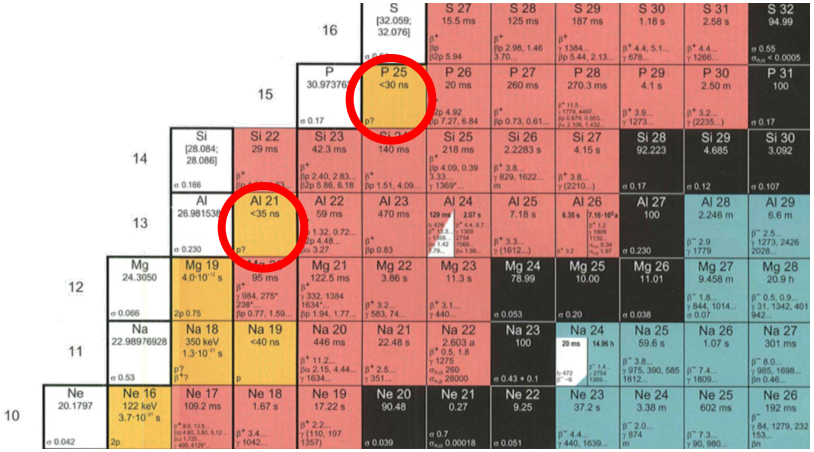


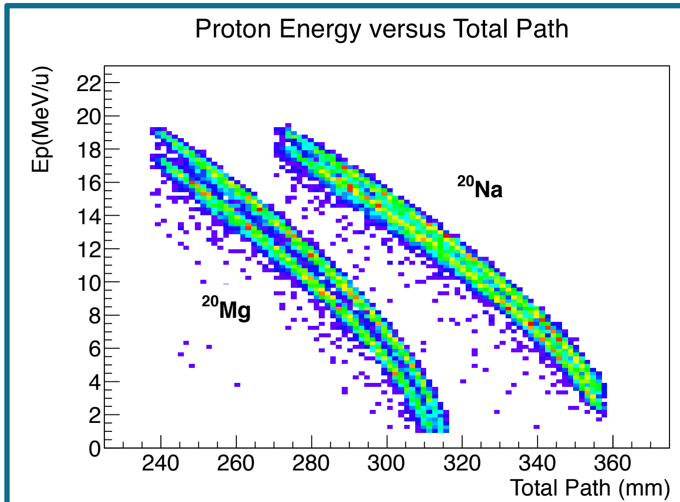


Physics I: resonant reactions

B. Fernández-Domínguez, USC

- **^{20}Mg+p→^{21}Al** elastic and inelastic
  Study of symmetry-breaking and
  3N-forces effects on
  - N=8 shell closure
  - Thomas-Ehrman shift
    of analogue states in mirror nuclei
  - widths of resonant states
  <u>Approved proposal</u> (USC) at
  HIE-ISOLDE 5.5 MeV/A

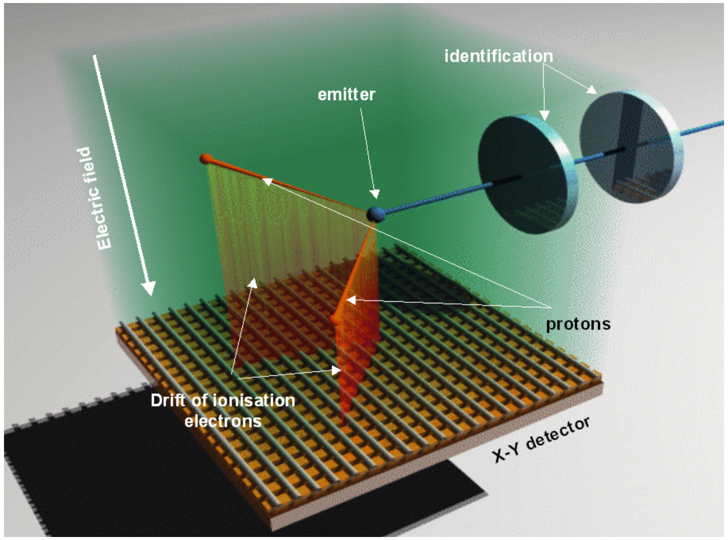




- **^{24}Si+p→^{25}P** 8 MeV/A at GANIL/LISE
  No data, probably unbound
  Candidate proton halo ($\pi s_{1/2}$)

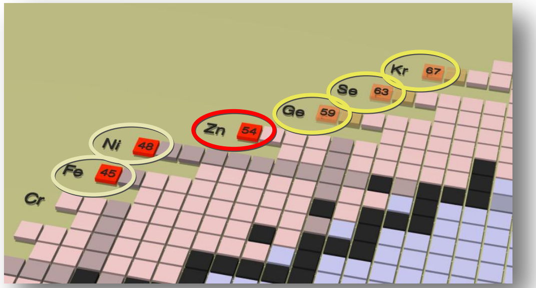
Physics II: decay

J. Giovinazzo, CENBG

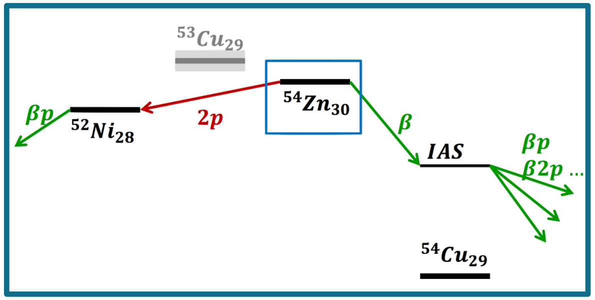


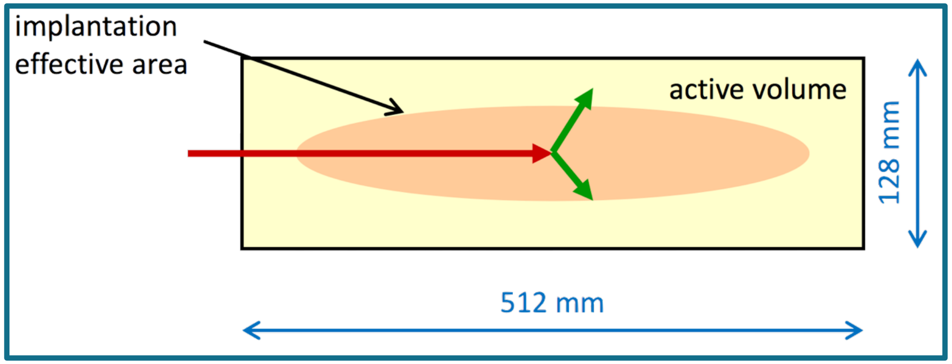
- Energy and angles of emitted particles
  → angular correlations
  sensitive to structure of the state
  and decay mechanism

- Known cases:
  ^{45}Fe, ^{48}Ni, ^{54}Zn



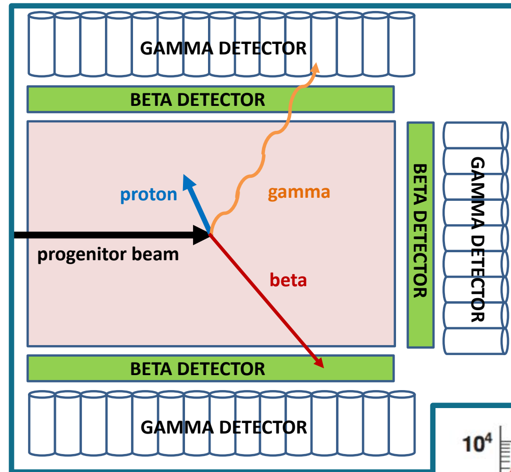
- ACTAR TPC: ^{54}Zn at GANIL/LISE





Physics II: decay

- Other processes of interest:
  βpα, β3p, β2p, βp
  Active target: particle identification and transparent to β's
- βp to study (p,γ) resonances (relevant to nuclear astrophysics)
- Example:
  βp-decay of ^{23}Al to study ^{22}Na(p,γ)^{23}Mg
  Nucleosynthesys in novae



A. Saastamoinen et al., PRC83 (2011) 045808

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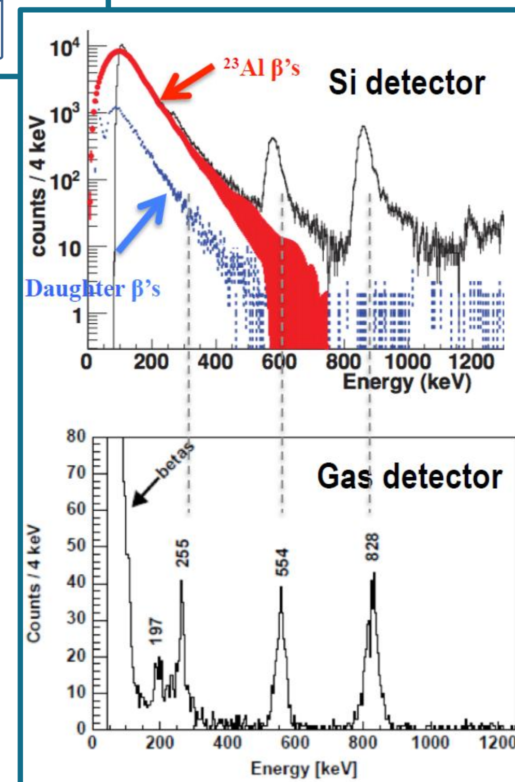
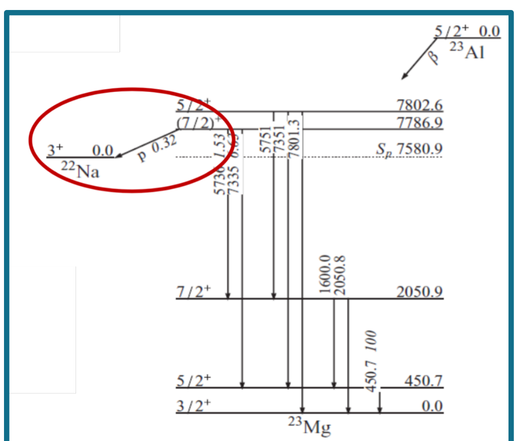
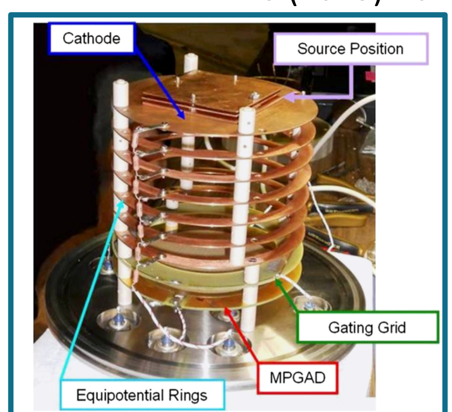




AstroBox

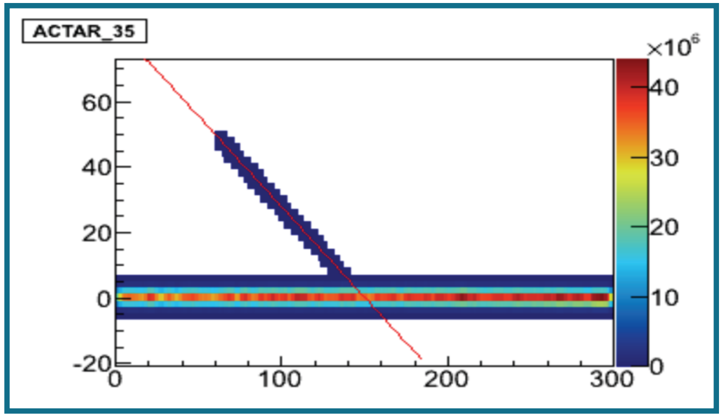
E. Pollacco et al., NIMA 723 (2013) 102



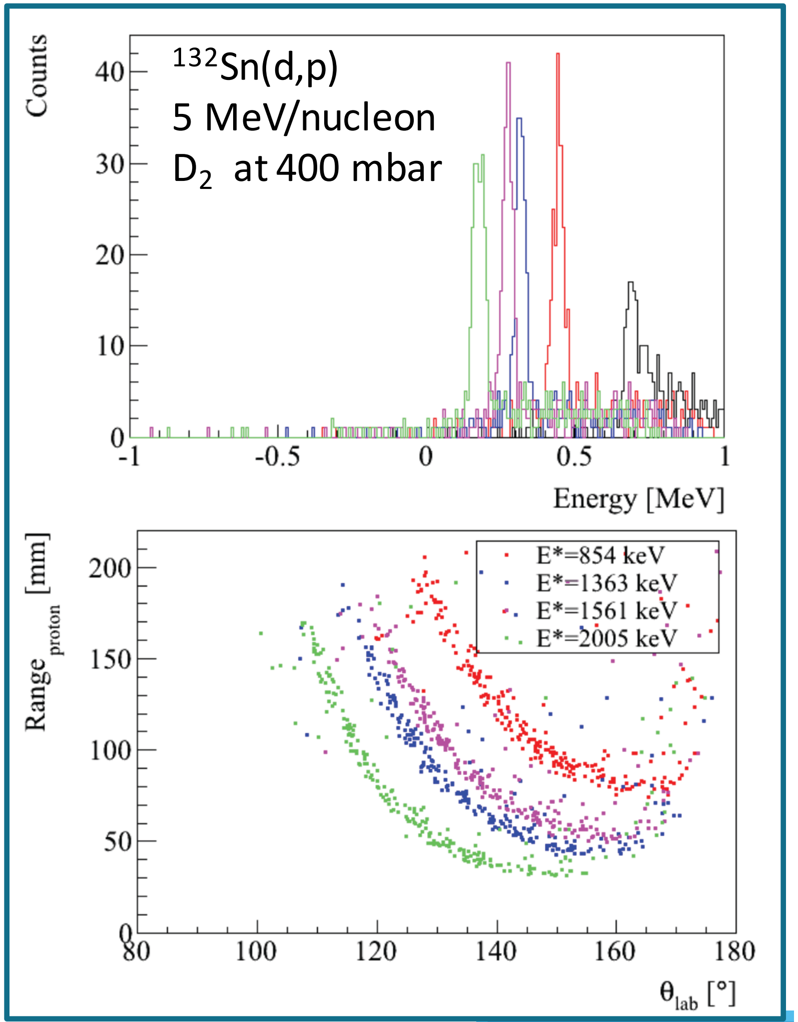
Physics III: transfer reactions

Characteristics of transfer reactions

- 1 mm vertex resolution
  → equivalent to 15 μg/cm² CD_2
- Total thickness ≈25 times larger
- Particles are stopped in gas
  or escape laterally
- Resolution ≈110 keV
  for particles stopped in gas



Source: ACTARSim Report,
D. Perez-Loureiro & G. Grinyer



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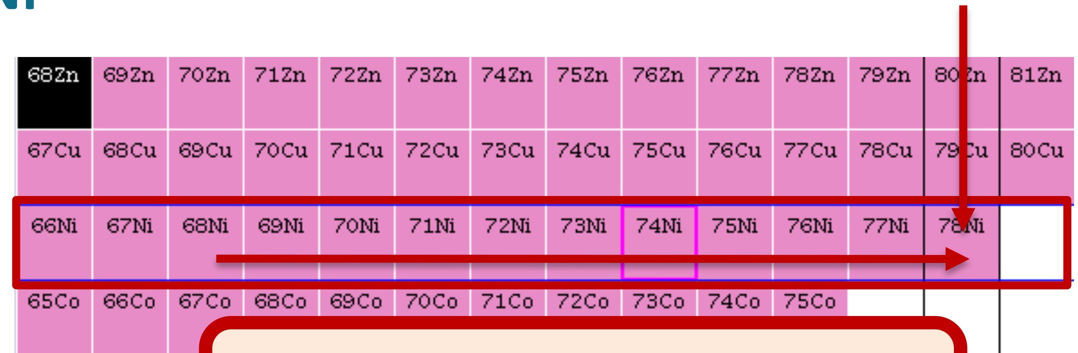
Physics III: transfer reactions

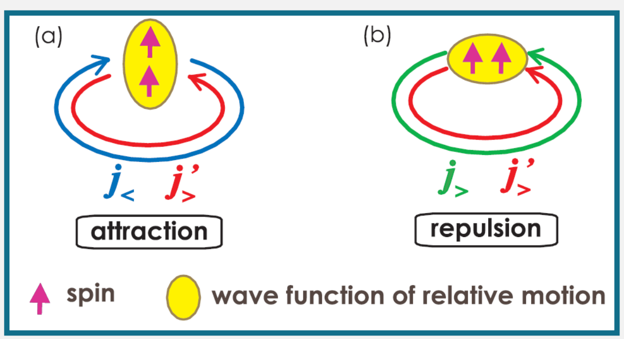
Shell evolution towards ^{78}Ni

- Migration of $\pi f_{7/2}$, $\pi f_{5/2}$ as $\nu g_{9/2}$ is filled
- Migration of $\nu g_{9/2}$ and $\nu d_{5/2}$ as $\pi f_{5/2}$ is emptied
- (Non-)magicity of N=40

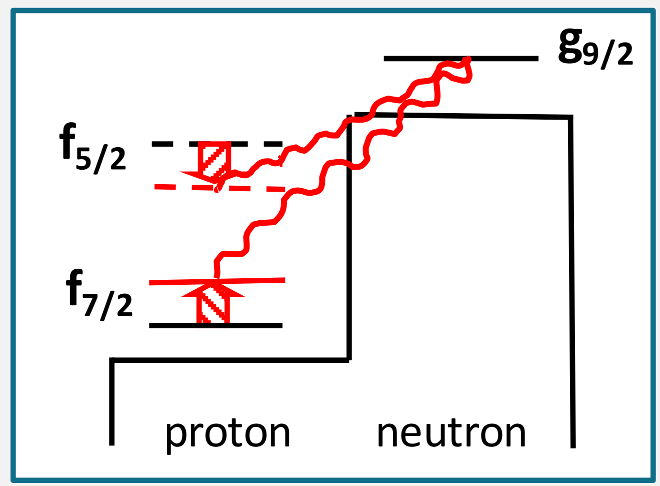


(d,p) and (d,^{3}He) transfers on ^{68}Ni, ^{70}Ni, ^{78}Zn, ^{80}Zn

- Tensor interaction (only if S=1)



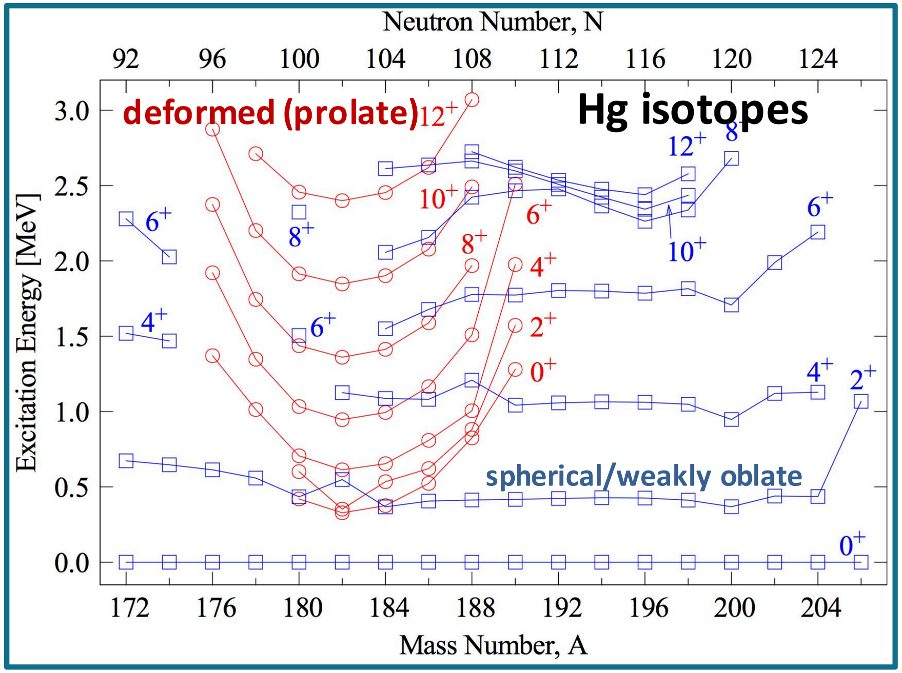
T. Otsuka et al., PRL 95 (2005) 232502



Physics III: transfer reactions

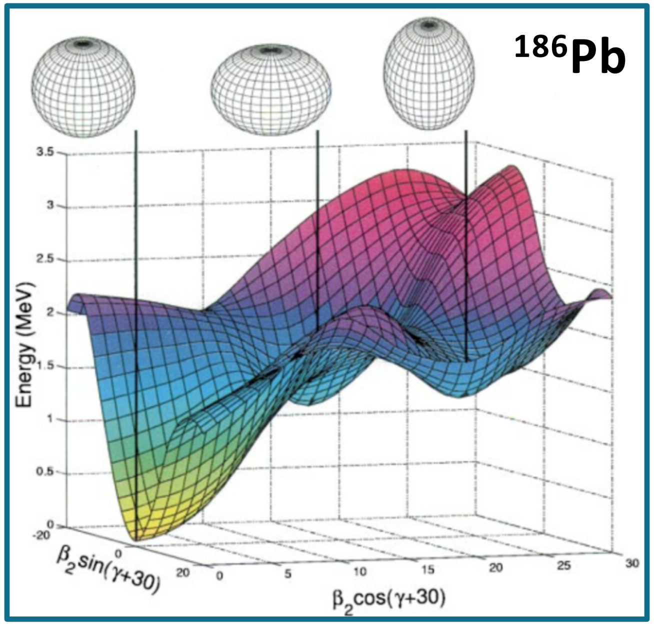
Shape coexistence "west" of ^{208}Pb

- States characterised by different shapes appear at low excitation energy
- Example: n-deficient Pb region
  ^{186}Pb triple-shape coexistence
  Hg nuclei: "parabolic intrusion" at mid-shell



Data: NNDC, figure courtesy of L. Gaffney
Original figure in R. Julin et al., J. Phys. G 27 (2001) R109

A. Andreyev et al., Nature 405 (2000) 430



(d,p) and (p,d) transfers on ^{184,185g,185m}Hg (possibly ^{182}Hg), ^{188}Pb, ^{196}Po

Physics III: transfer reactions

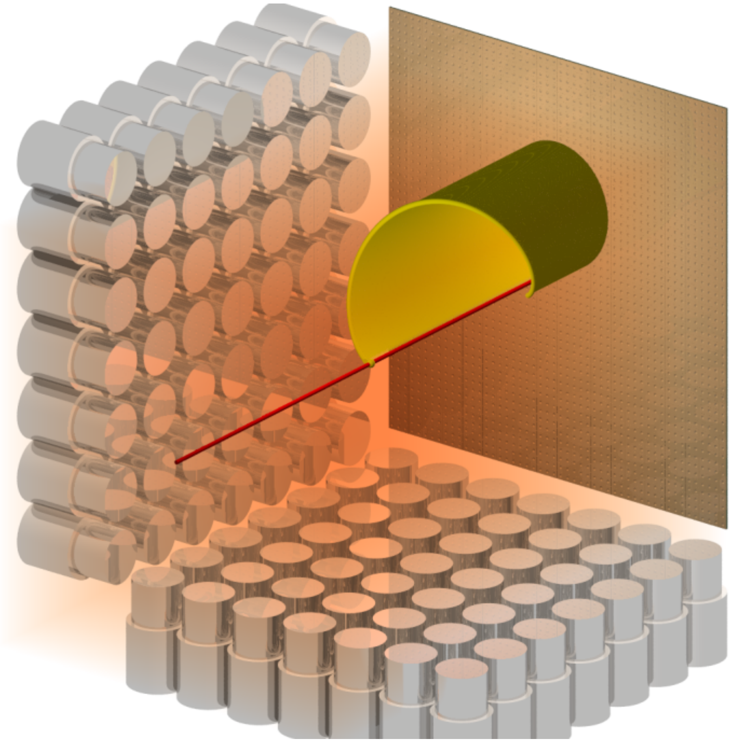
Adding γ-ray detection

Challenges

- Resolution
- Efficiency

→ Choices

- Active target axial configuration
- Magnetic field parallel
  to beam direction
  to confine emitted particles
  and minimize material
- $LaBr_3$ ($CeBr_3$) scintillators



Technical: place array of γ-ray detectors within the field

Physics III: transfer reactions

- Compare different solutions with respect to vacuum
- Compare electronics: GET tests
- Compare performances of different read-out methods: phototubes vs SiPM
- Efficiency measurements


See Cobus' talk

Further work / issues

- Validate simulations
- Determine spatial resolution needed for Doppler correction
- Determine final size of the detector
- Test in magnetic field

Physics IV: giant resonances

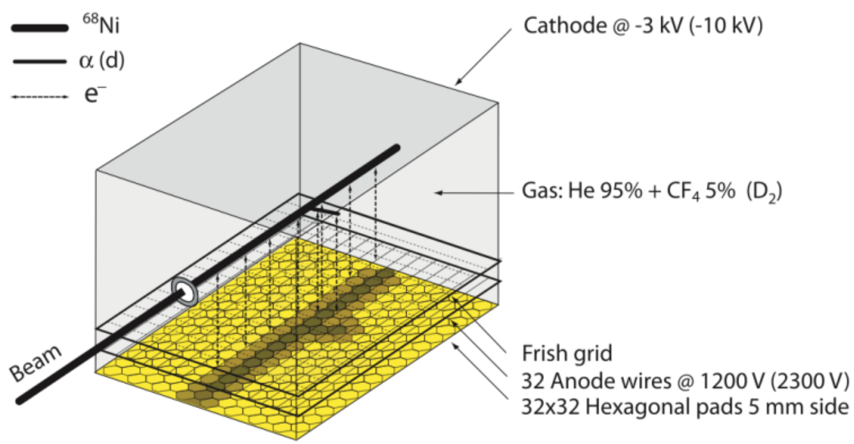
Investigations of collective modes: isoscalar resonances

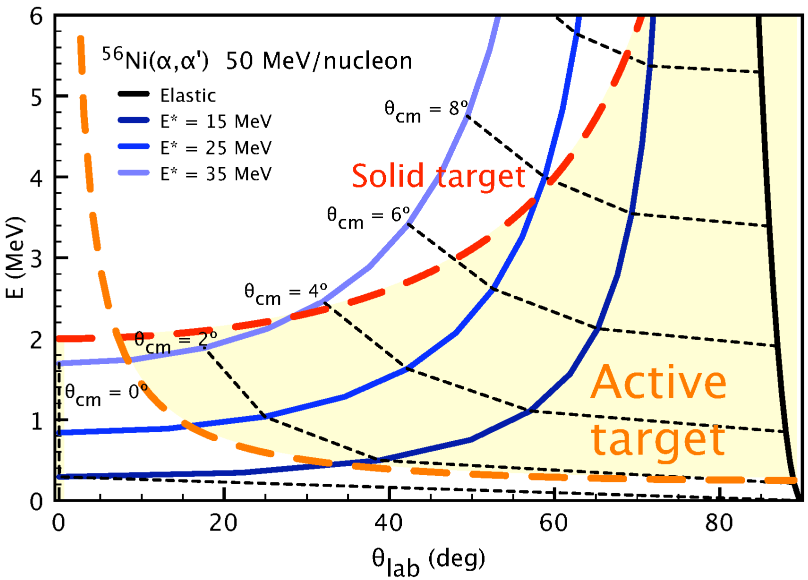
- Inelastic scattering at grazing angles: unique possibilities thanks to the low thresholds

- ^{56}Ni(d,d') GMR and GQR
  C. Monrozeau et al., PRL 100 (2008) 042501

- ^{68}Ni(d,d') and (α,α')
  GMR, GQR and soft monopole
  M. Vandebrouck et al., PRL 113 (2014) 032504
  M. Vandebrouck et al., PRC 92 (2015) 024316

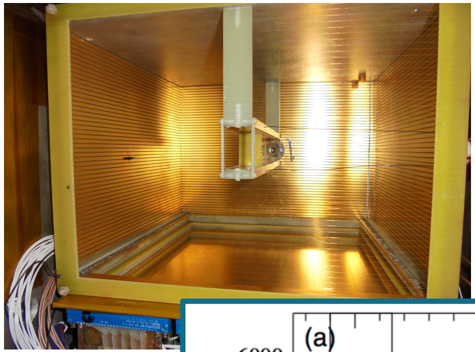
- ^{56}Ni(α,α') GMR and GDR
  S. Bagchi et al., PLB 751 (2015) 371

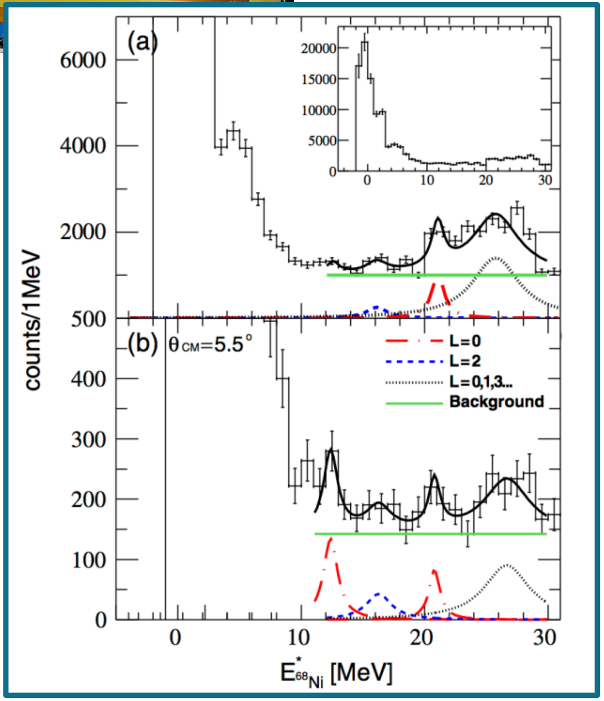




Physics IV: giant resonances

- Needs high beam intensities
  → mask the incoming beam
- Recoil traces very short
  → limited resolution

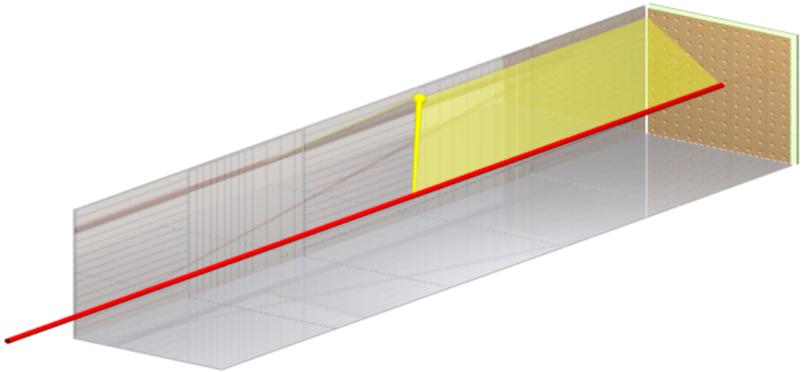




M. Vandebrouck et al.,
PRL 113 (2014) 032504

New design

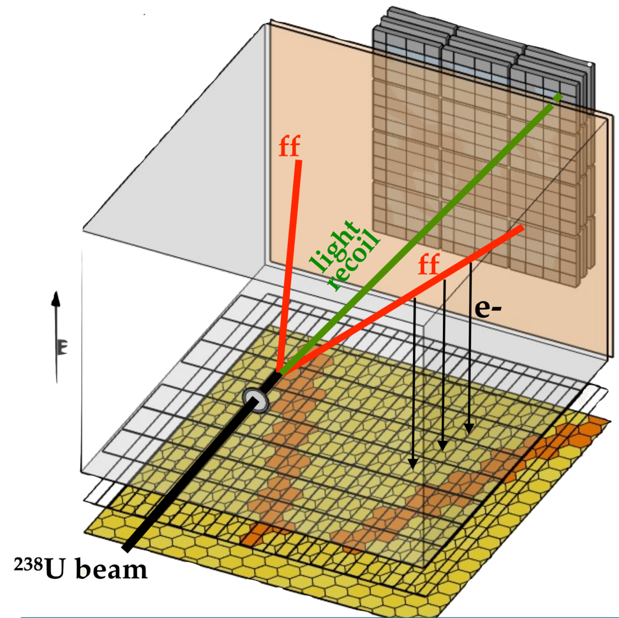
- axial geometry
- lower pressure → longer target
  angles measured from tracks, energy in Si

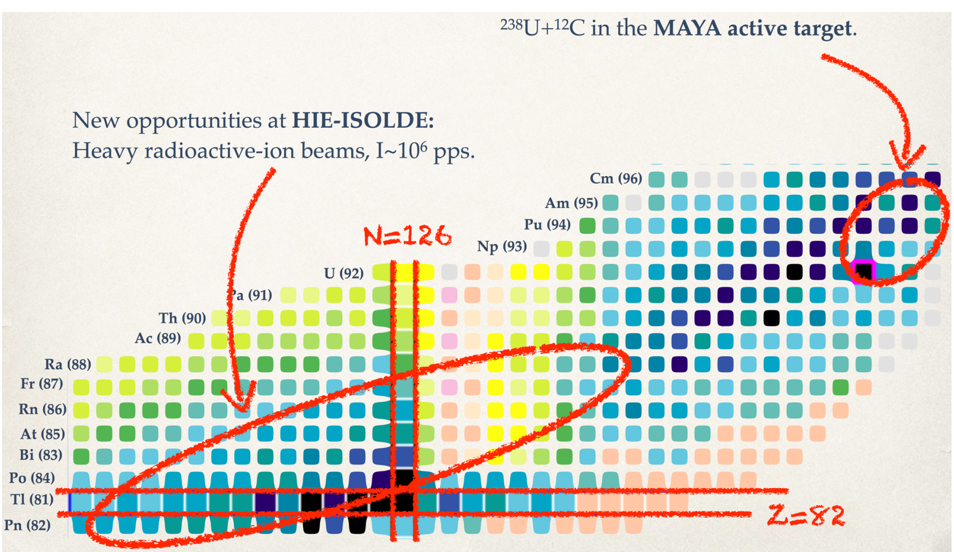


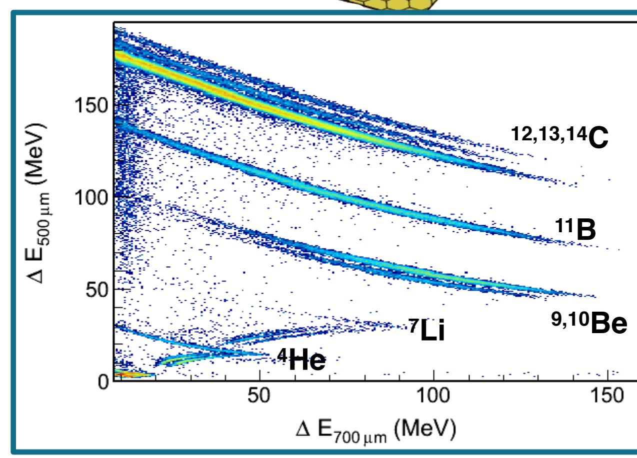
Physics V: transfer-induced fission

C. Rodríguez-Tajes, USC

- Fission studies relevant for: stability of superheavy nuclei, r-process nucleosynthesys, nuclear energy…
- Transfer-induced fission: access to new systems (neutron-rich and excited states)
- **^{238}U+^{12}C in Maya at GANIL/LISE**
- ^{193}Tl, ^{199}Bi, ^{201}At and ^{209}Fr(d,p) approved experiment at HIE-ISOLDE (M. Veselski, Bratislava)







Summary

Active target detectors provide unique opportunities in nuclear structure studies

- Radioactive beams:
  low intensity and inverse kinematics
  → Active target detectors:
  high luminosity, high resolution, low thresholds

- Versatile
  different gases and pressures
  selective sensitivity

- New frontiers:
  - higher counting rates
  - higher dynamic range
  - higher resolution
  - combine with various auxiliary detectors

European Research Council
Established by the European Commission